US011203092B2

(12) **United States Patent**
Read

(10) **Patent No.: US 11,203,092 B2**
(45) **Date of Patent: Dec. 21, 2021**

(54) **METHOD FOR FABRICATING VACUUM FIXTURING USING GRANULAR MEDIA**

(71) Applicant: **Technical Tooling L.L.C.**, Tacoma, WA (US)

(72) Inventor: **Robert W. Read**, Lakewood, WA (US)

(73) Assignee: **Technical Tooling L.L.C.**, Tacoma, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 98 days.

(21) Appl. No.: **16/822,981**

(22) Filed: **Mar. 18, 2020**

(65) **Prior Publication Data**

US 2020/0238459 A1 Jul. 30, 2020

Related U.S. Application Data

(60) Division of application No. 15/963,928, filed on Apr. 26, 2018, now Pat. No. 10,596,668, which is a continuation of application No. 15/913,616, filed on Mar. 6, 2018, now Pat. No. 10,583,536, which is a continuation of application No. 14/881,925, filed on Oct. 13, 2015, now Pat. No. 10,300,569.

(60) Provisional application No. 62/063,816, filed on Oct. 14, 2014.

(51) **Int. Cl.**

B23Q 3/08	(2006.01)
B23Q 3/06	(2006.01)
B29C 70/44	(2006.01)
B29K 263/00	(2006.01)
B29K 63/00	(2006.01)

(52) **U.S. Cl.**
CPC ***B23Q 3/088*** (2013.01); ***B23Q 3/065*** (2013.01); ***B29C 70/44*** (2013.01); *B29K 2063/00* (2013.01); *B29K 2263/00* (2013.01)

(58) **Field of Classification Search**
CPC . B29C 33/0011; B29C 33/38; B29C 33/3842; B29C 33/3857; B23Q 3/088; B23Q 3/08; B23Q 3/065; H01L 21/68; H01L 21/683; H01L 21/6838; Y10T 279/11; B25B 11/00; B25B 11/005; B25B 11/007
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,617,719	A	11/1952	Stewart
2,625,886	A	1/1953	Browne
3,146,148	A	8/1964	Mitchella et al.
3,187,444	A	6/1965	Lehmann et al.

(Continued)

OTHER PUBLICATIONS

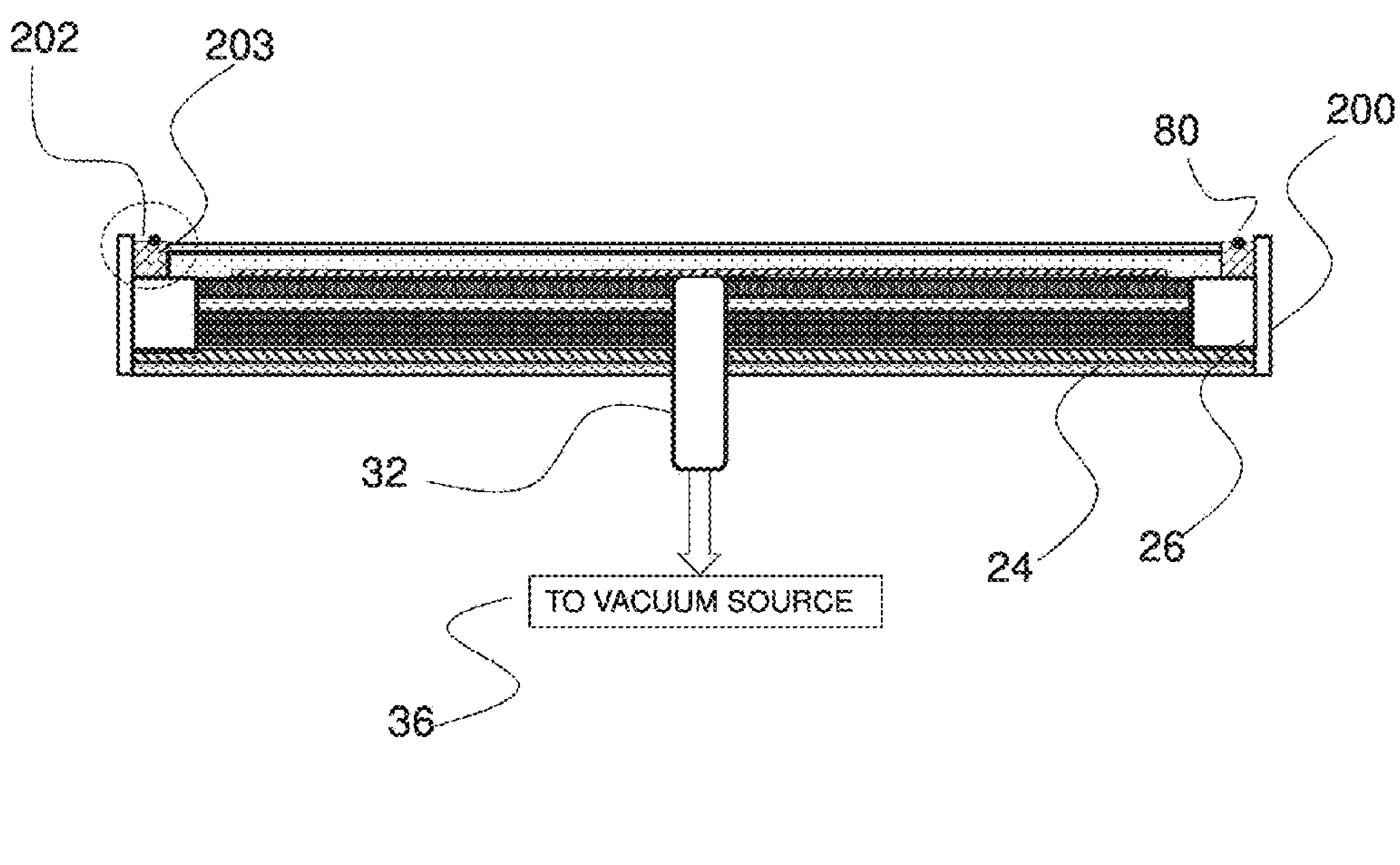
Handymath.com. Percentage by Weight to Percentage by Volume Conversion Calculator. https://www.handymath.com/cgi-bin/dnstywtvol.cgi?submit=Entry (Year: 2019).

Primary Examiner — Tyrone V Hall, Jr.
(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

A method for fabricating vacuum tooling is disclosed using porous granular media. A sheet of steel webbing is affixed to a frame. A plurality of layers of fiberglass is affixed to the webbing. A vacuum port is installed through the webbing and plurality of layers of fiberglass. A granular media is mixed with epoxy to form a granular mixture. The granular mixture is layered over the plurality of layers of fiberglass to form a flat surface and machined for uniformity before sealing.

20 Claims, 12 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

3,689,025	A	9/1972	Kiser
3,834,687	A	9/1974	Martin et al.
3,953,013	A	4/1976	Griffith et al.
3,968,885	A	7/1976	Hassan et al.
4,029,517	A	6/1977	Rand
4,063,705	A	12/1977	Vodra
4,091,643	A	5/1978	Zucchini
4,355,937	A	10/1982	Mack et al.
4,367,140	A	1/1983	Wilson
4,406,596	A	9/1983	Budde
4,474,199	A	10/1984	Blaudszun
4,521,995	A	6/1985	Sekiya
4,541,717	A	9/1985	Itamoto et al.
4,549,467	A	10/1985	Wilden et al.
4,597,228	A	7/1986	Koyama et al.
5,576,030	A	11/1996	Hooper
5,645,474	A	7/1997	Kubo et al.
5,730,764	A	3/1998	Williamson et al.
6,012,883	A	1/2000	Engwall et al.
6,032,997	A	3/2000	Elliott et al.
6,309,587	B1	10/2001	Gniatvzyk et al.
6,679,758	B2	1/2004	Bright et al.
7,021,635	B2	4/2006	Sheydayi
7,434,590	B2	10/2008	Sheydayi
7,446,020	B2	11/2008	Nakamura
7,654,887	B2	2/2010	Ishikawa et al.
7,938,466	B2	5/2011	Joguet et al.
8,298,473	B2	10/2012	Dull et al.
8,403,188	B2	3/2013	Platsch
10,300,569	B2	5/2019	Read
10,583,536	B2	3/2020	Read
10,596,668	B2	3/2020	Read
2003/0194947	A1	10/2003	Bright et al.
2005/0161861	A1	7/2005	Lammers et al.
2006/0073677	A1	4/2006	Nakamura
2006/0130875	A1	6/2006	Sheydayi
2007/0063453	A1*	3/2007	Ishikawa H01L 21/6838 279/3
2009/0008825	A1	1/2009	Eberth

* cited by examiner

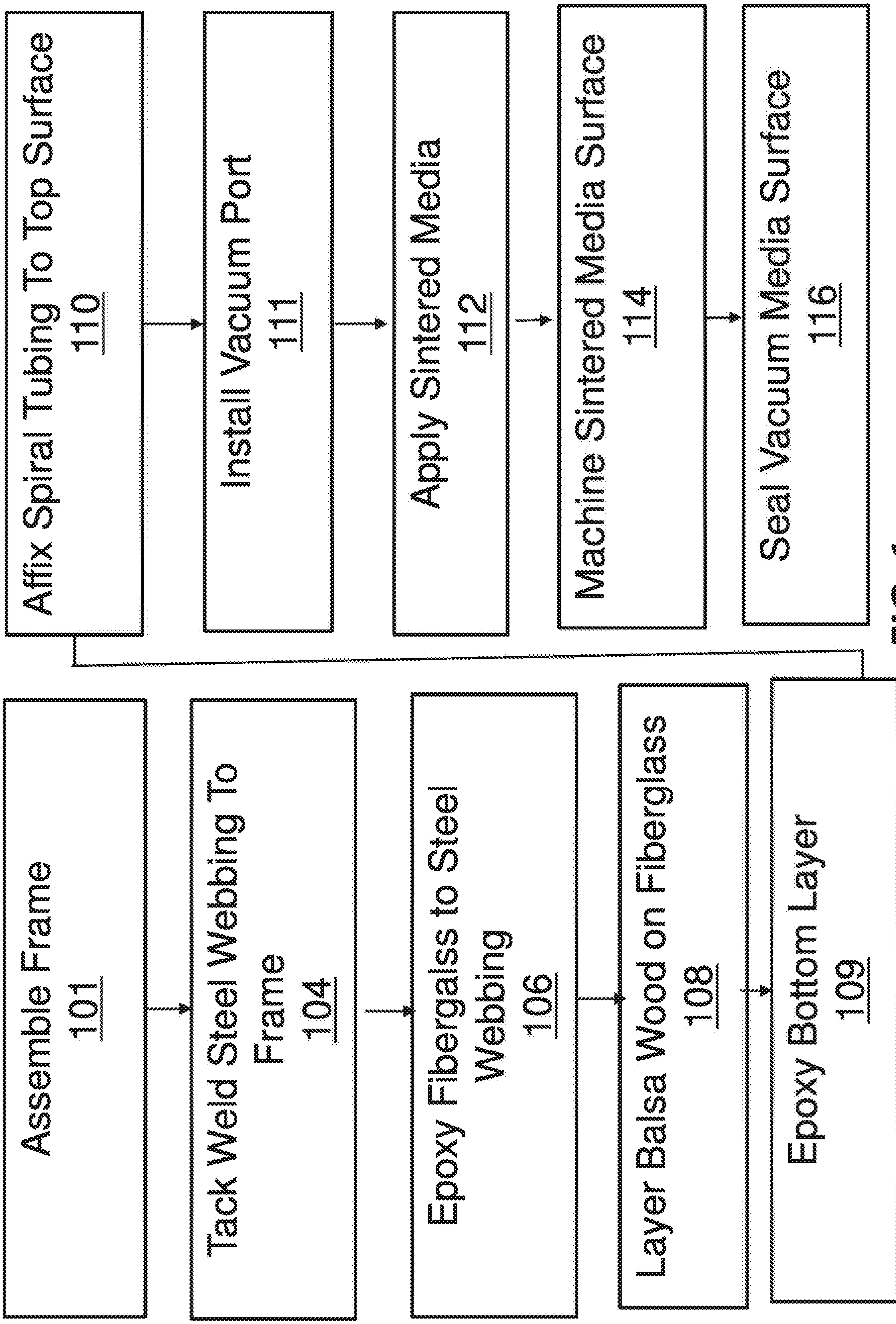

Assemble Frame
101
Tack Weld Steel Webbing To Frame
104
Epoxy Fibergalss to Steel Webbing
106
Layer Balsa Wood on Fiberglass
108
Epoxy Bottom Layer
109
Affix Spiral Tubing To Top Surface
110
Install Vacuum Port
111
Apply Sintered Media
112
Machine Sintered Media Surface
114
Seal Vacuum Media Surface
116

FIG. 1

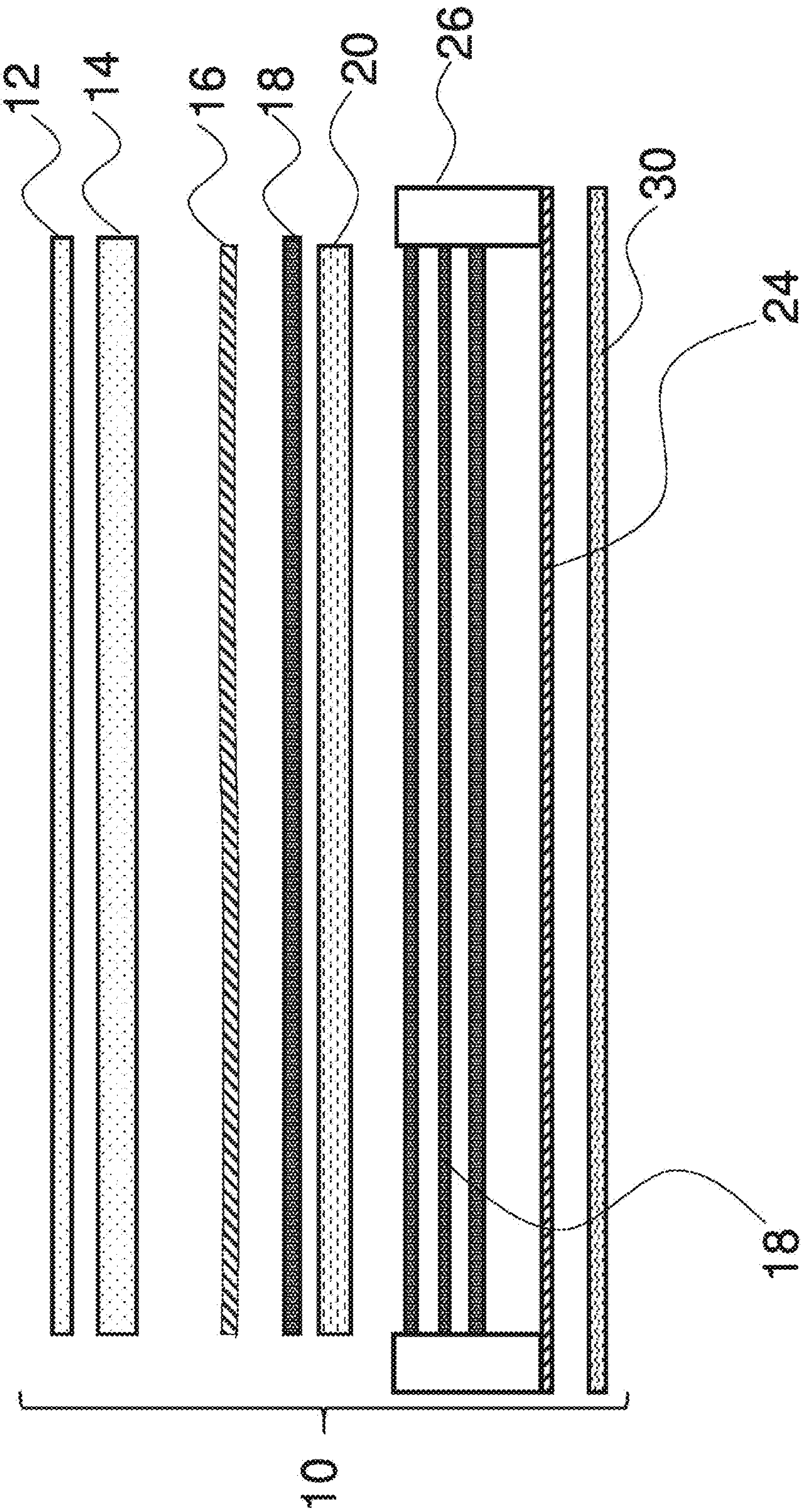


FIG. 2

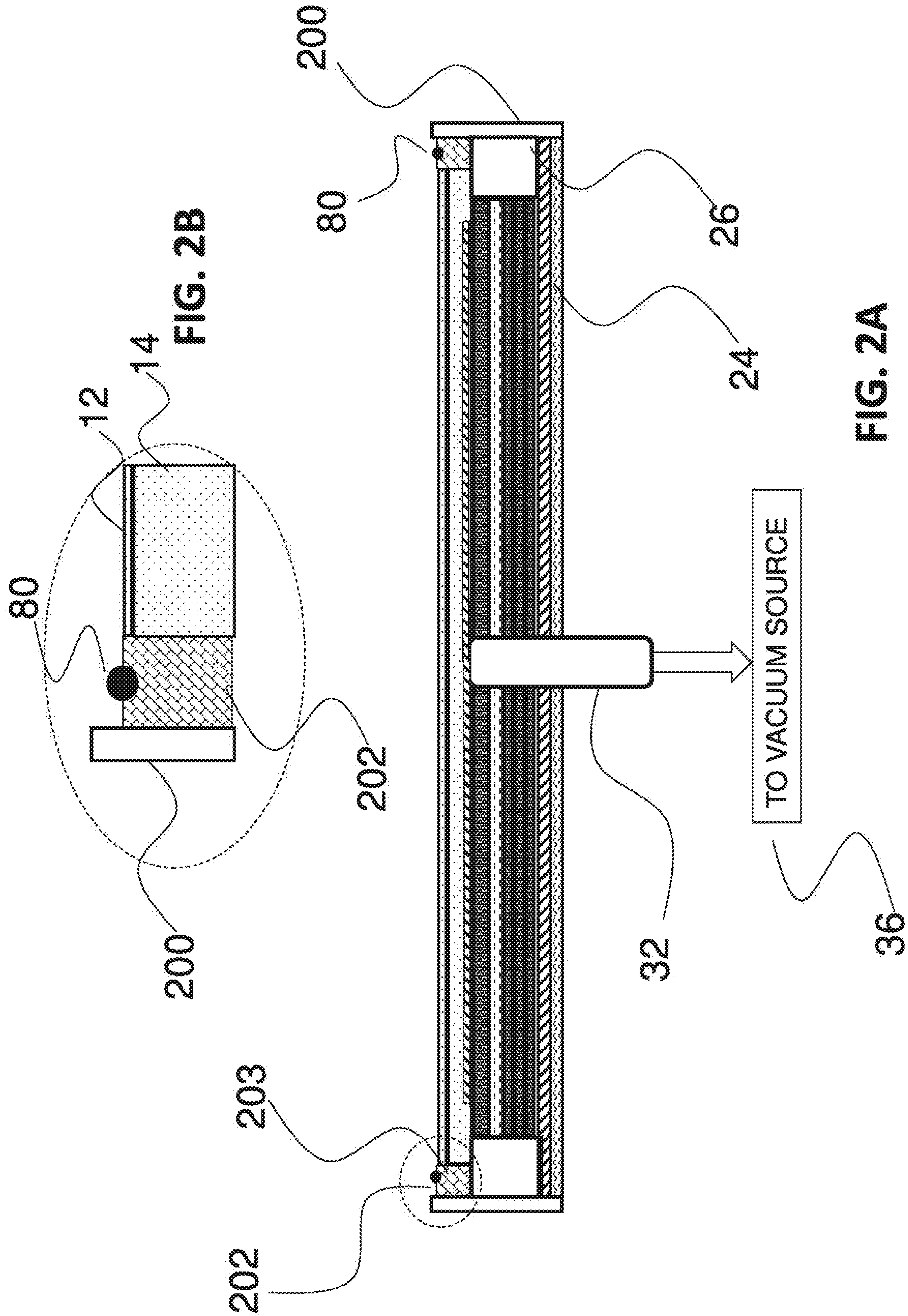


FIG. 2B

FIG. 2A

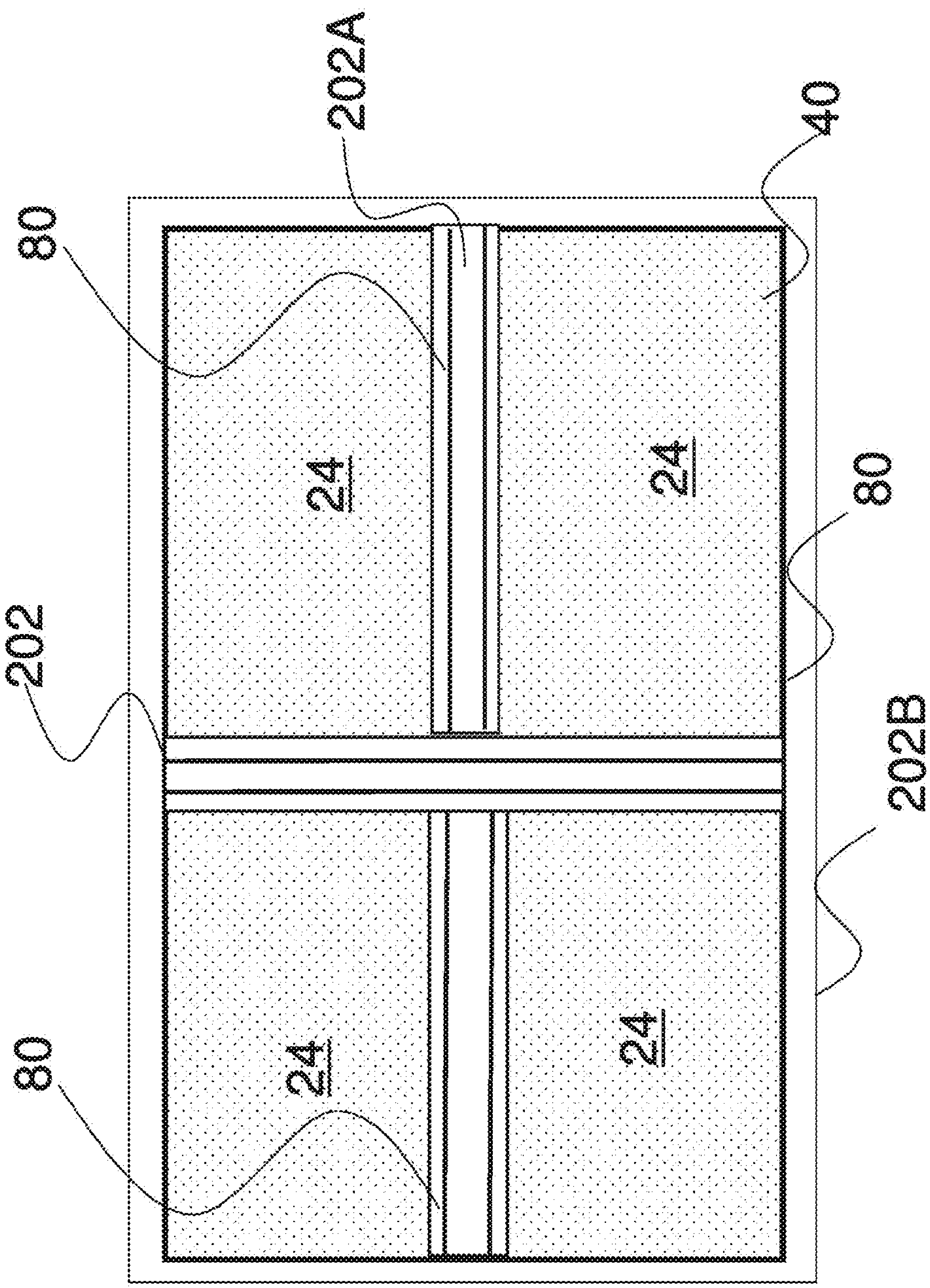


FIG. 3

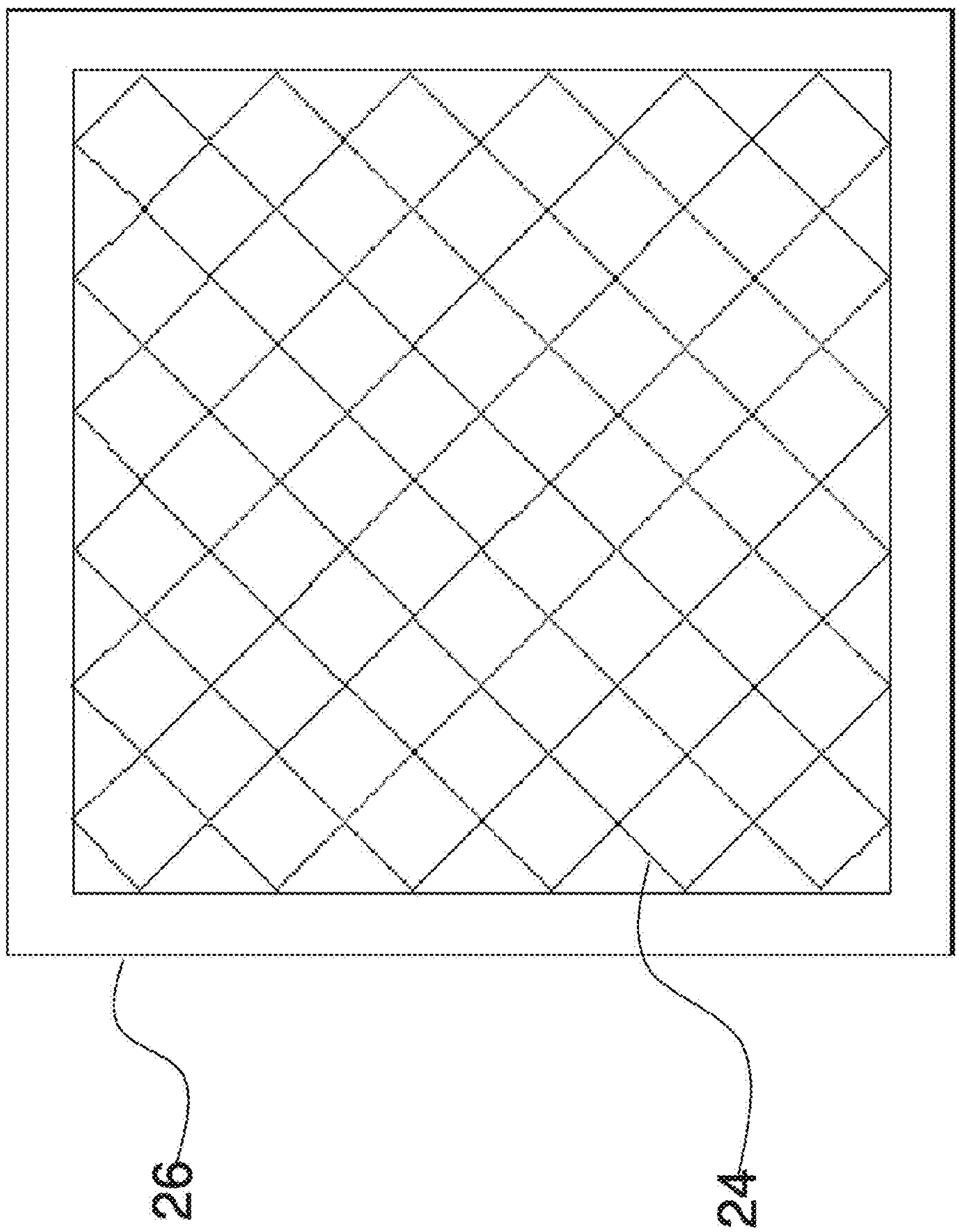


FIG. 4

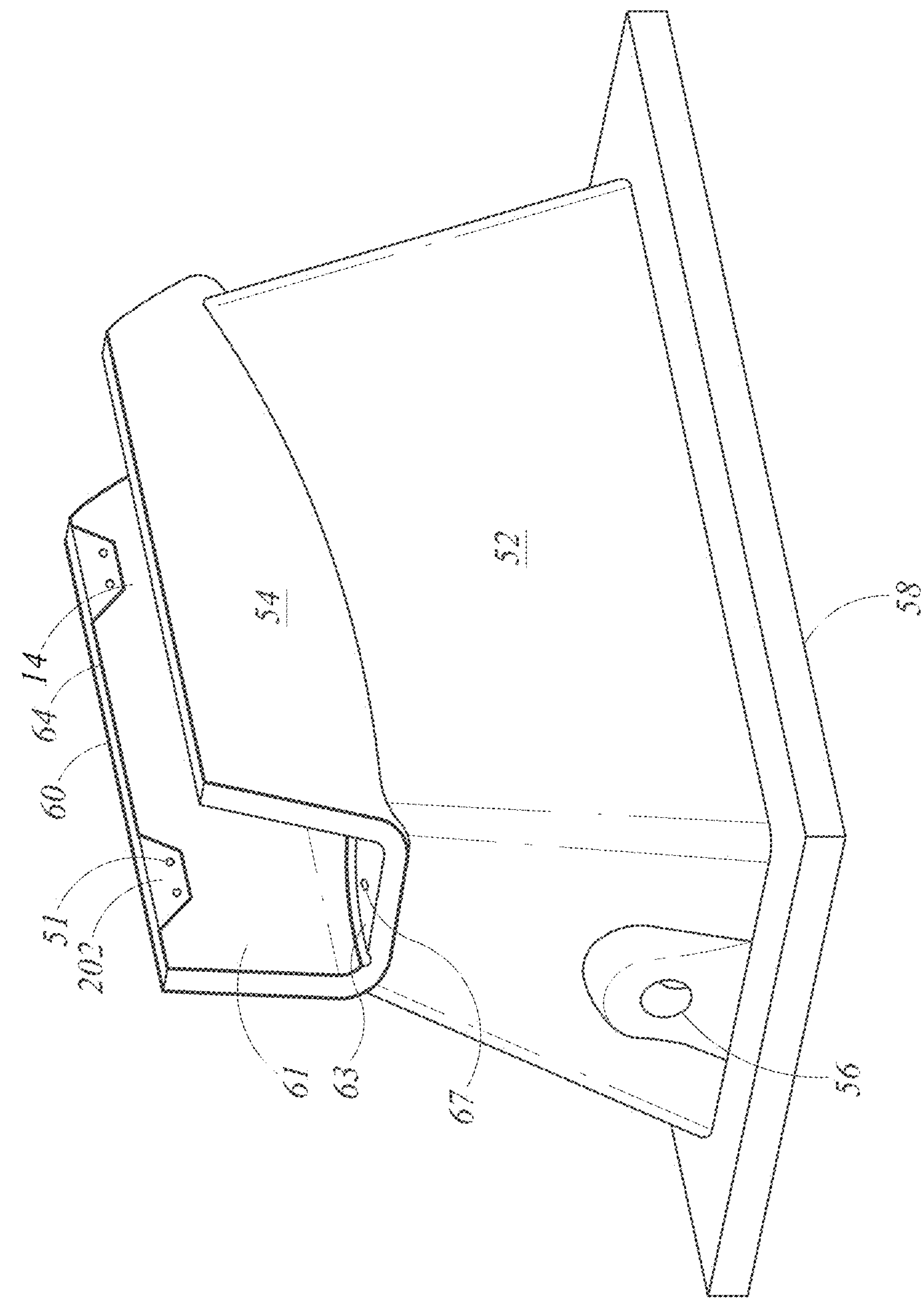


FIG. 5

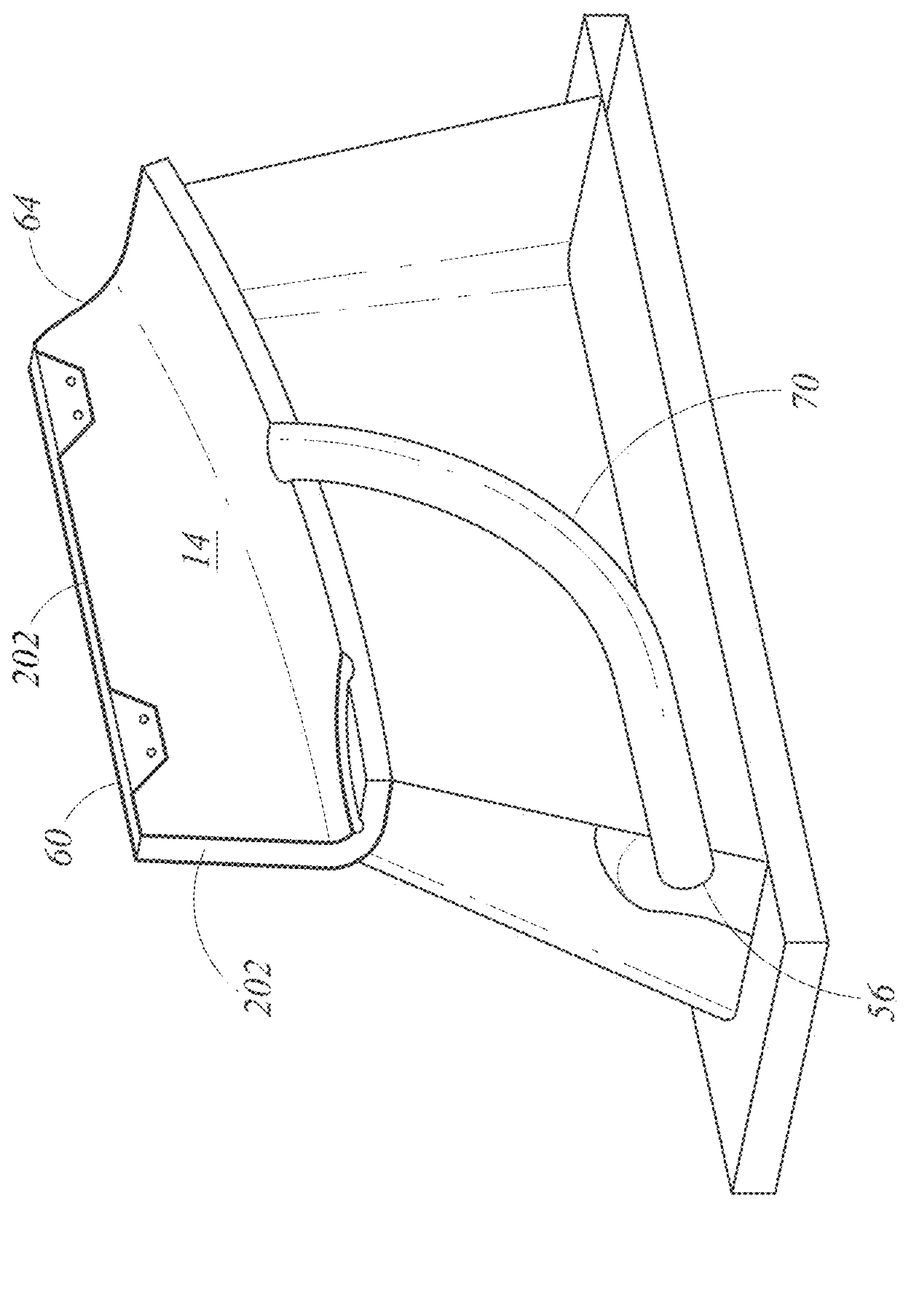


FIG. 6

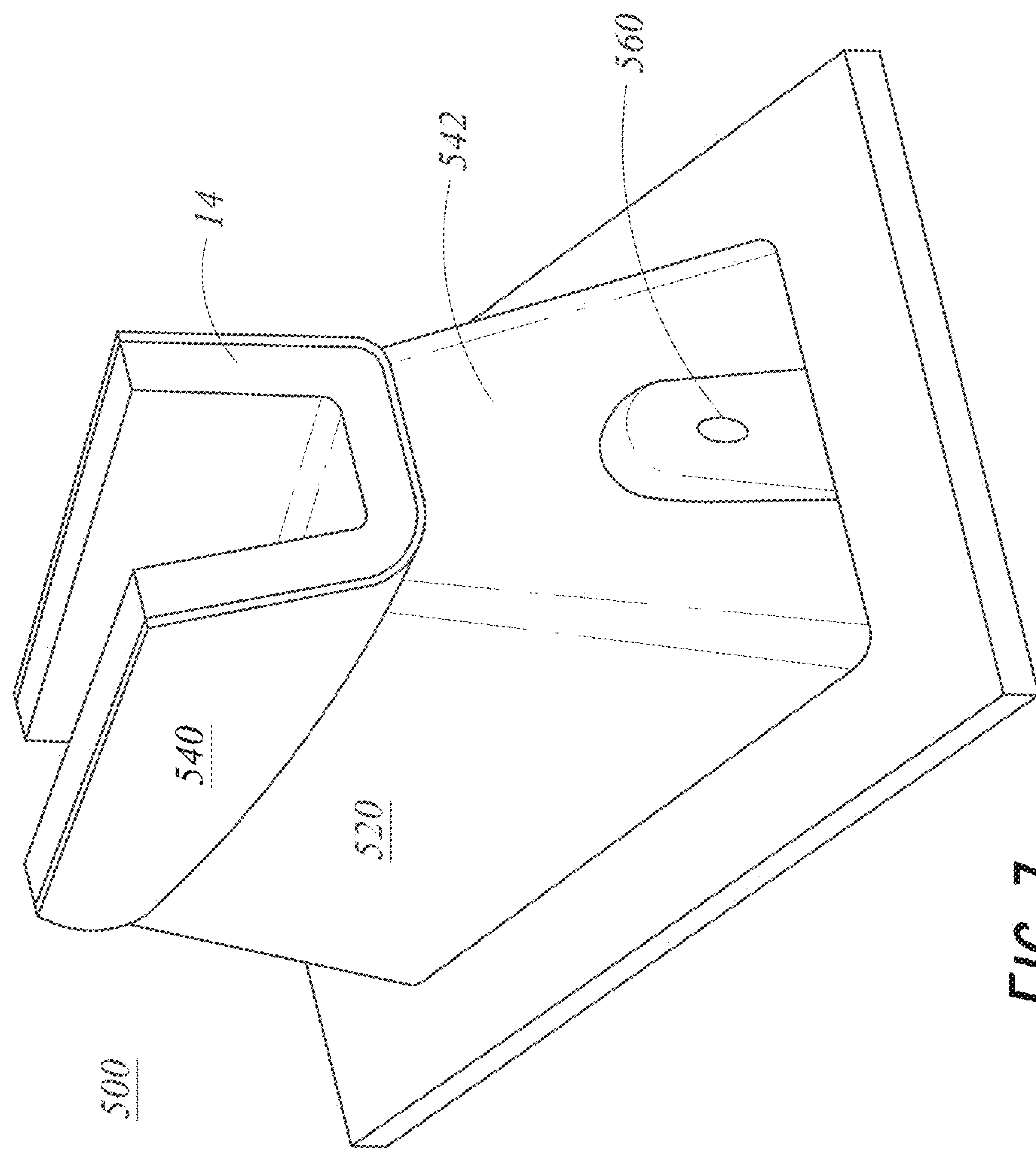


FIG. 7

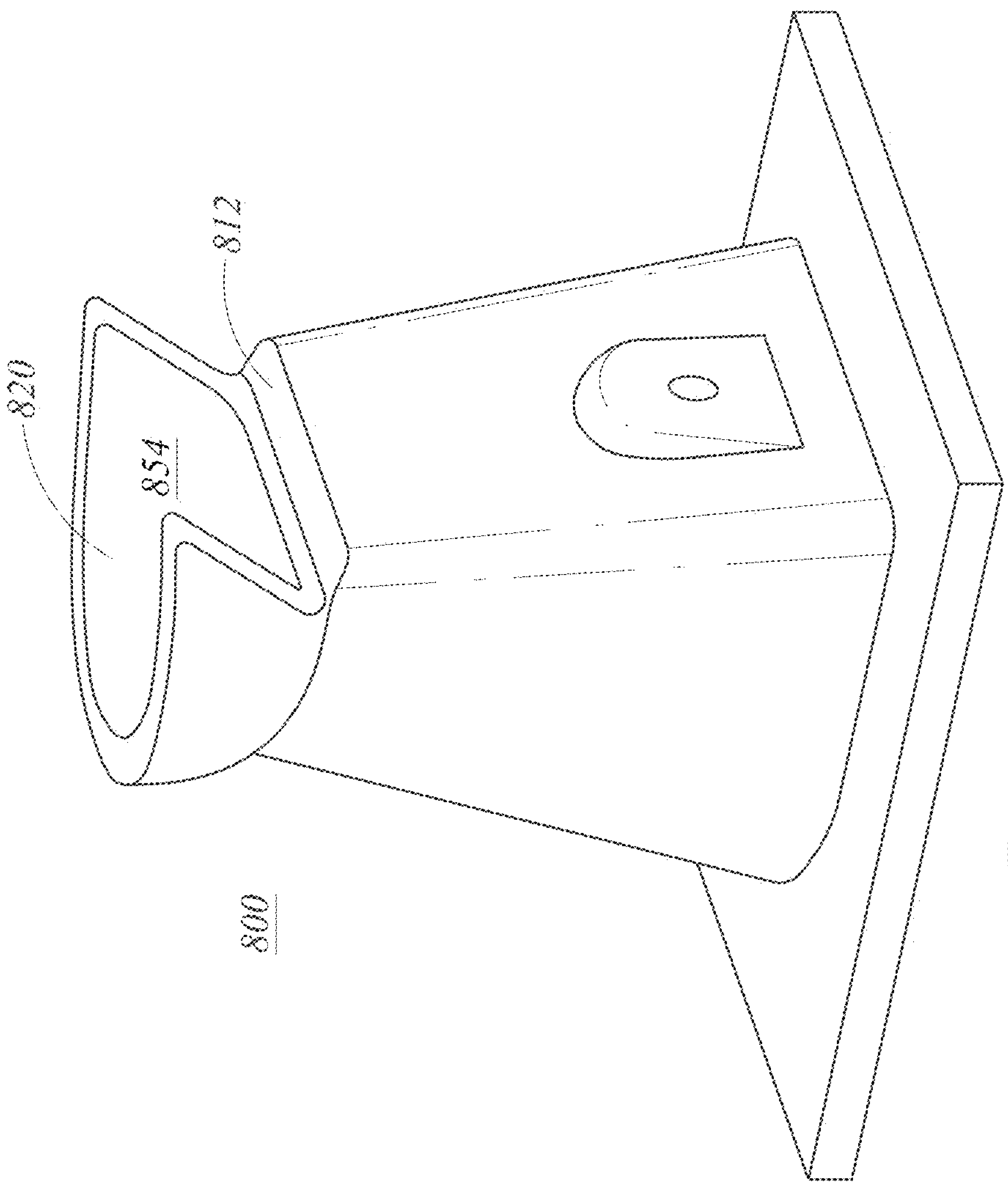


FIG. 8

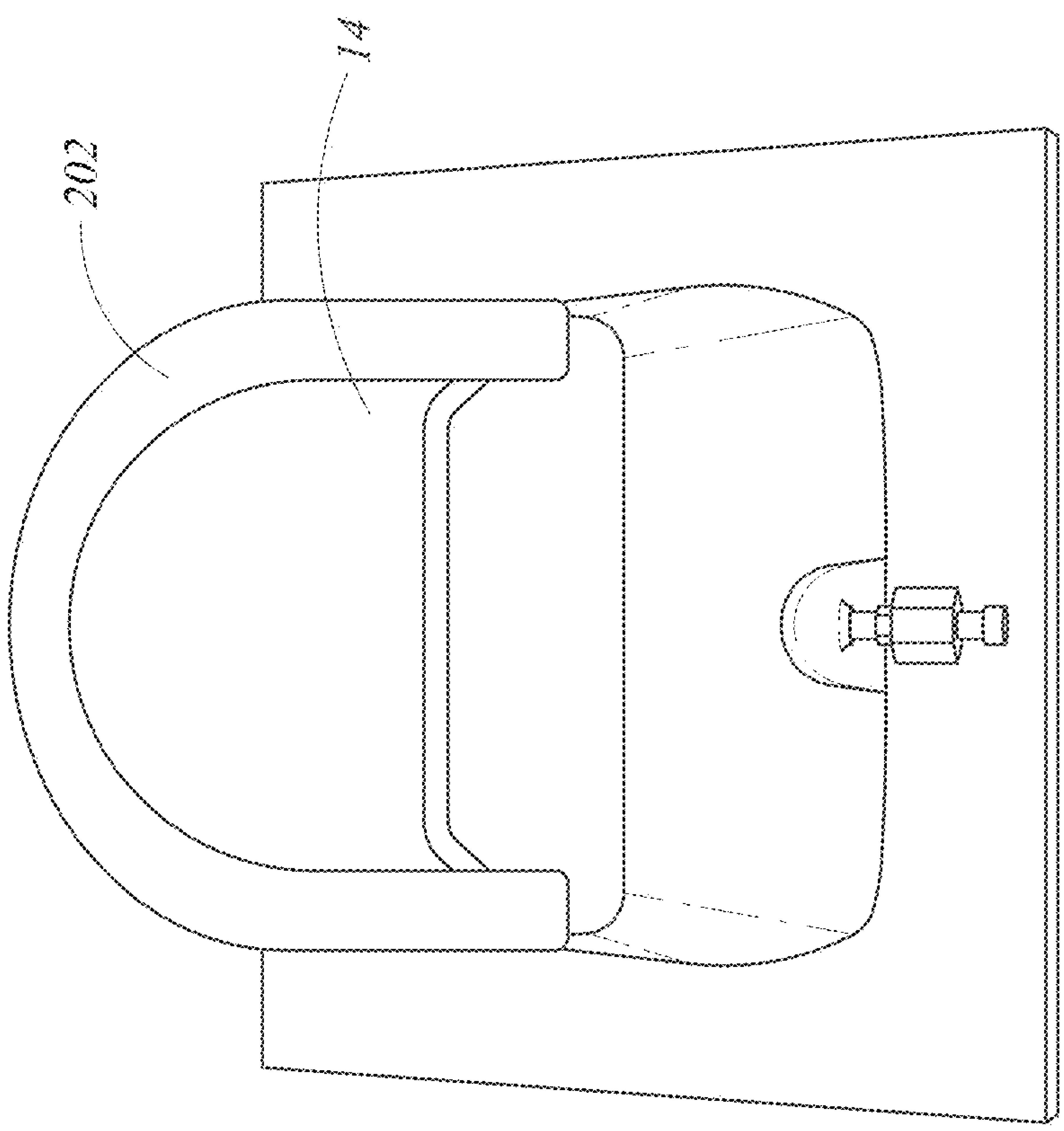


FIG. 9

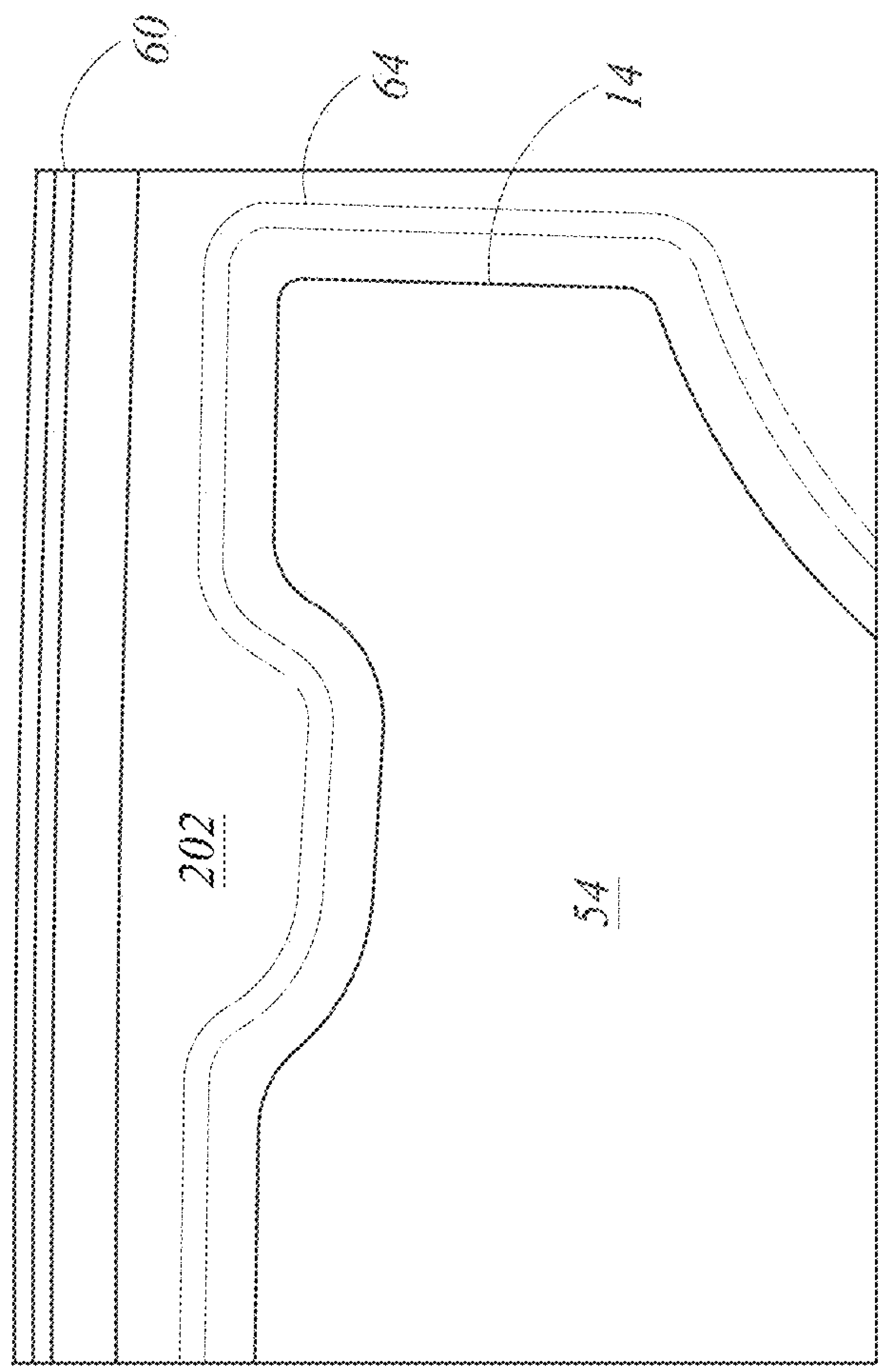


FIG. 10

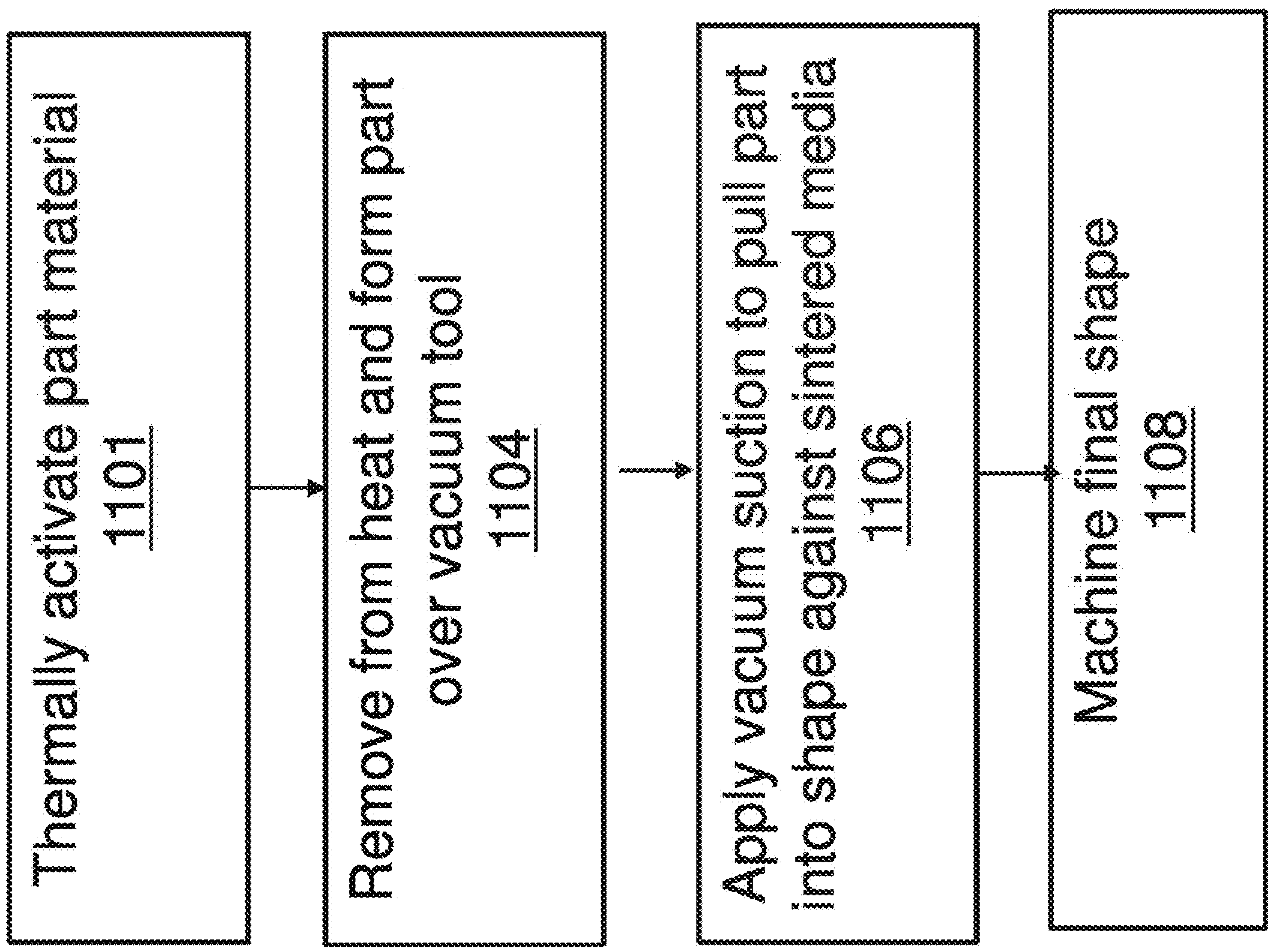

Thermally activate part material
1101
Remove from heat and form part over vacuum tool
1104
Apply vacuum suction to pull part into shape against sintered media
1106
Machine final shape
1108

FIG. 11

METHOD FOR FABRICATING VACUUM FIXTURING USING GRANULAR MEDIA

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 15/963,928, entitled "METHOD FOR FABRICATING VACUUM FIXTURING USING GRANULAR MEDIA" and filed on Apr. 26, 2018, which in turn is a continuation of U.S. application Ser. No. 15/913,616, now U.S. Pat. No. 10,583,536, entitled "METHOD FOR FABRICATING VACUUM FIXTURING USING GRANULAR MEDIA" and filed on Mar. 6, 2018, which in turn is a continuation of U.S. application Ser. No. 14/881,925, now U.S. Pat. No. 10,300,569, entitled "METHOD FOR FABRICATING VACUUM FIXTURING USING GRANULAR MEDIA" and filed on Oct. 13, 2015, which in turn claims the benefit of U.S. Provisional Application No. 62/063,816, entitled "METHOD FOR FABRICATING VACUUM FIXTURING USING SINTERED MEDIA" and filed Oct. 14, 2014, the disclosures of which are incorporated herein by reference.

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to methods for holding thin metal and/or composite surfaces for machining, and, more particularly, to a method for making a vacuum tooling fixture from a porous granular material.

Current manufacturing demands faced by the aerospace industry require thinner, stronger parts in order to meet constantly more demanding standards for lowering costs, improving safety and increasing fuel mileage. As a result, manufacturers are faced with machining thin walled parts using high speed processes. Machining complex shapes with walls having thickness in the range of, for example, 0.010" to 0.060" (0.025 to 0.15 cm). Such parts are prone to wander on a machining fixture when being drilled or milled, for example.

Some have unsuccessfully tried to address this problem using vacuum methods including the use of materials like micro-balloons. Unfortunately, these materials are relatively costly and hard to shape into intricate parts. Because epoxy resin is typically used to bind round micro-balloons comprising such older materials it cannot easily be shaped or repaired if damaged. A significant drawback is that, since such materials have inherently smooth surfaces, they do not prevent slippage of many thin-walled parts while the parts are undergoing machining.

The present invention provides a method for making vacuum tooling fixtures that solve the aforesaid problems. For the first time, tile inventors herein have discovered and developed a new and useful gritty and/or abrasive vacuum media that secures thin-walled parts in place for machining, that is easily repairable when damaged, and is low cost compared to prior methods and materials.

For example, in an advantage over previously available systems the vacuum media of the present invention is made of epoxy and gritty and/or abrasive granular material which may easily be formed and patched as desired. Thus cuts or holes drilled into the granular media may be repaired as necessary for continued use.

BRIEF SUMMARY OF THE DISCLOSURE

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This summary is not intended to identify key features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

In one embodiment a method for fabricating a vacuum table is disclosed using porous granular media. A sheet of steel webbing is affixed to a frame. A plurality of layers of fiberglass is affixed to the webbing. A vacuum port is installed through the webbing and plurality of layers of fiberglass. A granular media is mixed with epoxy to form a granular mixture. The granular mixture is layered over the plurality of layers of fiberglass to form a flat surface and machined for uniformity before sealing.

In one aspect the granular media consists essentially of sintered iron grit or epoxy resin.

In another aspect a course of spiral wrap tubing is encompassed by the granular mixture.

In another aspect the course of spiral wrap tubing is configured in a serpentine pattern, a circular pattern, a branching pattern and/or an oval pattern.

In another aspect an additional stiffener is added between the granular mixture layer and the plurality of layers of fiberglass.

In another aspect the additional stiffener comprises a layer of balsa wood and another layer of fiberglass.

In another aspect a tooling fixture with vacuum granular media is disclosed including a pedestal and a part holding section attached atop the pedestal. A vacuum port is coupled to the part holding section and a fiberglass lining is applied to the inside of the part holding section. A porous granular media and epoxy mixture are positioned in communication with the vacuum port. A urethane barrier seals the porous granular media, and an O-ring groove is cut in the urethane barrier.

In yet another aspect of the invention, a method for vacuum forming of thermally pliable parts using porous granular media is disclosed. The method includes:

- providing a tooling fixture with porous granular media comprising:
  - a pedestal,
  - a part holding section attached atop the pedestal,
  - a vacuum port coupled to the part holding section,
- a fiberglass lining applied to the inside of the part holding section,
  - a porous granular media and epoxy mixture in communication with the vacuum port,
  - a urethane barrier sealing the porous granular media, and
  - an O-ring groove in the urethane barrier;
- thermally activating a part using a heating source;
- removing the part from the heating source;
- placing the part into the tooling fixture; and
- conforming the part to the tooling fixture by applying vacuum pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically shows a block diagram of a process for fabricating a vacuum table using porous granular media.

FIG. 2 schematically shows an exploded cut-away side view of an example of a vacuum table made in accordance with the principles disclosed herein.

FIG. 2A schematically illustrates a cut-away side view of an example of an assembled vacuum table with a vacuum tube attached.

FIG. 2B schematically illustrates a detail of a partial cut-away side view of an example of the assembled vacuum table of FIG. 2A.

FIG. 3 schematically shows a top view of an example of an assembled vacuum table.

FIG. 4 schematically shows a top view of an example of expanded steel mesh material used in the assembly of a vacuum table.

FIG. 5 schematically shows an example of a tooling fixture made for use with the vacuum granular media as disclosed herein.

FIG. 6 schematically illustrates a cut-away side view of an example of a tooling fixture made for use with the vacuum granular media as disclosed herein.

FIG. 7 shows an example of a tooling fixture made with the vacuum granular media as disclosed herein prior to machining the granular material for the addition of the urethane layer.

FIG. 8 shows an example of a tooling fixture made with the vacuum granular media as disclosed herein prior to machining the part holding section for the addition of the urethane layer.

FIG. 9 shows an example of the tooling fixture of FIG. 8 after addition of the urethane layer.

FIG. 10 shows a more detailed side view of an example of a tooling fixture of FIG. 6 made with the vacuum granular media as disclosed herein.

FIG. 11 schematically shows a block diagram of a process for vacuum forming of thermally pliable parts using porous granular media.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The examples presented herein are for the purpose of furthering an understanding of the invention. The examples are illustrative and the invention is not limited to the example embodiments.

Unless the context requires otherwise, throughout the specification and claims which follow, the word "comprise" and variations thereof, such as, "comprises" and "comprising" are to be construed in an open, inclusive sense that is as "including, but not limited to."

Reference throughout this specification to "one example" or "an example embodiment," "one embodiment," "an embodiment" or combinations and/or variations of these terms means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present disclosure. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

Definitions

Generally, as used herein, the following terms have the following meanings unless the context suggests otherwise:

"Vacuum granular media" or "porous granular media" means any of gritty non-silica granular media including sintered iron, epoxy resin granules and/or other irregularly-shaped, gritty and/or abrasive granular material capable of transmitting a distributed vacuum force through a layer of the media having a thickness, for example, in the range of about 0.5 to about 2.0 inches. "Vacuum source" means a source for providing a vacuum pressure of, for example, at least about 14.7 psi.

"Fluid communication" means connected to as to allow for pressure flow or air flow.

Vacuum Table with Granular Media

Referring now to FIG. 1, a block diagram of a process for fabricating a vacuum table using porous granular media in accordance with the principles disclosed herein is schematically shown. A granular media vacuum table has been made by the inventors according to the following steps:

At step 101 a frame is made from a framing material such as, for example, steel in the shape of the table as desired. Usually the table is a rectangular table wherein a plurality of sections of vacuum surfaces may be installed. Hollow steel tubing may be advantageously employed and cut to the lengths desired depending on the application. The tubing is welded together or otherwise attached to form the frame.

At step 104 a sheet of, for example, expanded steel webbing is tack welded to the frame. Then, at step 106, a plurality of layers of fiberglass are affixed epoxy to the steel webbing. For added strength, at step 108 an additional stiffener, such as, for example, a layer of balsa wood may be affixed to the top of the fiberglass and itself covered with another layer of fiberglass. A layer of epoxy may be affixed to the bottom of the webbing at step 109 for added rigidity and stability.

At step 110 a course of spiral wrap tubing may optionally be affixed to the top surface of the top fiberglass layer as, for example, by using hot melt glue or an equivalent method. The course of spiral tubing is selected to disperse the vacuum according to the vacuum media surface area. For surface areas less than six inches square, spiral tubing may not be needed. For larger areas the tubing may be advantageously laid out to form a serpentine pattern, a circular pattern, branching pattern, an oval or the like so as to distribute the vacuum force uniformly and form vacuum sections of about six square inches or less as a general rule. When needed depending on the application, sections of commercially available spiral tubing of about ⅜ inch can be connected using T connectors or straight connectors. At step 111, or before the spiral tubing is applied, as is most convenient, a vacuum port is installed by cutting a suitable aperture through the laminated materials and adding a flange, pipe or other vacuum attachment mechanism to the bottom of the table as shown herein below. The spiral tubing should be in fluid communication with the vacuum introduced through the vacuum tube that is the vacuum is allowed to flow through the course of spiral tubing.

Then, at step 112, a mixed formulation of vacuum granular media is applied over the spiral tubing to form the top surface of the vacuum table. The layer of granular vacuum media is then applied over and covers the spiral wrap tubing and the laminated surface. At step 114 the vacuum media surface is machined to a smooth, flat finish. At step 116 the granular vacuum media is spray-painted to seal the surface and encapsulate small loose particulates.

Referring now to FIG. 2, an exploded cut-away side view of an example of a vacuum table made in accordance with the principles disclosed herein is schematically shown. A vacuum table 10 includes a top film 12, a layer of porous granular material **14**, optional spiral tubing **16**, an optional layer of coated fiberglass **18**, an optional layer of stiffener **20**, a plurality of layers of coated fiberglass **18**, a tack-welded sheet of expanded steel webbing **24**, a frame **26** and a bottom layer of epoxy resin **30** with filler for added stability.

Although the porous granular material may comprise various types of materials, in one useful embodiment, the granular material comprises a non-silica abrasive in the form of a non-silica, fine abrasive black sand available from Kleen Blast company located in Danville Calif. In one example a fine abrasive is rated at about 35 grit size. Such abrasives are commonly used for sand blasting and may comprise sintered iron. Another useful type of abrasive is finally crushed walnut shell however, this has the drawback of absorbing moisture and is also heat sensitive. The granular vacuum media may advantageously be composed of general-purpose epoxy and abrasive. The ratio of epoxy to sand in one example is about 8% epoxy to about 92% abrasive. One useful type of epoxy is made by Dura technologies. 80 LS-25AT, thixed. In one useful embodiment, the fiberglass used to laminate the table comprises 20 ounce woven fiber glass cloth which is commercially available. The top film **12** may comprise any useful sealer such as spray paint, 30 epoxy and the like. To ensure penetration into the media the sealer may be applied under vacuum conditions.

In another useful example, the granular material may advantageously comprise an epoxy resin formed into granular particles. One example of a method for making granulated particles from epoxy resin follows the steps below:

1. Epoxy resin in liquid form is poured into a container to form ¼" sheets;
2. The sheets are allowed to harden;
3. The hardened sheets are broken into small pieces using a hammer mill such as is used in commercial mining;
4. The pieces are milled down to about 0.060 to 0.100 thousandths of an inch or to about a 36 grit; and
5. The grit is mixed with liquid epoxy as described herein and cast into a rough shape and then machined as desired.

One advantage of using the aforedescribed granular materials like sintered media and epoxy resin is that they do not absorb moisture and will not swell when exposed to humid or damp environments.

Referring now to FIG. **2**A, a cut-away side view of an example of an assembled vacuum table with a vacuum tube attached is schematically illustrated. During assembly, a vacuum hose or pipe **32** is inserted up through a hole **33** cut through the lamented surface. The hose **32** is coupled to a vacuum source **36** as indicated by direction arrow **34** to allow the vacuum to suction air through the granular media **14**. Any part resting on the surface of the granular media will be held in place by the suction and the gritty surface of the granular media.

Referring now to FIG. **2**B, a detail of a partial cut-away side view of an example of the assembled vacuum table of FIG. **2**A is schematically illustrated. Aluminum or steel plates **200** may be used to brace the vacuum table components during final assembly. The edges of the top layers of paint **12** and granular media **14** may be machined away to provide a channel **203** around 30 the vacuum table. A layer of urethane **202** is poured into the channel **203** to form a buffer around the perimeter of the vacuum table or a vacuum table section as the case may be. An O-ring groove is cut, molded or milled into the urethane layer and an O-ring **80** is affixed inside the O-ring groove to provide a vacuum seal with any flat surface placed on the vacuum table when activated by powering on a coupled vacuum source **36**. The urethane layer may itself include an edge that advantageously protrudes above the surface of the coated granular media to provide a buffer or edge for tooling plates or the like when being located on the table for machining.

Referring now to FIG. **3**, a top view of an example of an assembled vacuum table is schematically shown. This example includes a plurality of vacuum sections **40** separated by a barrier, such as a layer of urethane **202**. Each of the vacuum surfaces are milled to a flatness in the same horizontal plane as the others and coated as described above. Each of the vacuum surfaces will also be separately and directly coupled to one or more vacuum sources (as shown above). Each vacuum section **40** may be surrounded by 15 interior **202**A and exterior urethane barriers **202**B. The exterior urethane barrier **202**B may uniformly protrude above each vacuum surface **40** to allow tooling plates to be positioned onto the surface using it as a mechanical guide or block. A plurality of O-rings **80** are installed in the urethane barriers to seal the perimeter of each vacuum surface **40**. While four vacuum surfaces are shown, those skilled in the art having the benefit of this disclosure will recognize that the number of surfaces incorporated into a vacuum table can vary as is desired.

In a useful embodiment the vacuum sections **40** together with the exterior and interior urethane barriers may be constructed to have a standardized surface area to match the size of standard tooling plates. For example, the vacuum sections may be sized to accommodate 12×12 inch, 12×24 inch or 24×24 inch plates and so on as desired.

Referring now to FIG. **4**, a top view of an example of expanded steel mesh material used in the assembly of a vacuum table is schematically shown. The expanded steel sheet **24** is formed of webbing **25** and is commercially available in various thicknesses. Also shown is the frame **26** constructed of, for example, hollow steel tubes. In some embodiments other materials may be substituted for the expanded steel webbing. These may include webbing or mesh made from steel, plastic, nylon, polyethylene, aluminum, composites, metal and combinations thereof.

Tooling Fixture with Granular Media

Referring now to FIG. **5**, an example of a tooling fixture made for use with the vacuum granular media as disclosed herein is schematically shown. A tooling fixture **50** includes a pedestal **52**, a part holder **54**, a vacuum port **56** and a base **58**. The pedestal **52** and part holding section **54** are machined from a commercially available block closed-cell polystyrene foam such as the trademarked brand Styrofoam®. In one embodiment foam rated at 3.5 lb. per ft^3 density was employed. In fabricating the tooling fixture the foam block is cut generally in the shape of the part to be held for machining with extra room for the vacuum media to be applied. After cutting the block into shape, a fiberglass lining **60** is applied to the inside of the part holding section **54**. The interior **61** comprises a machined section of granular media and epoxy mixture **14** located **20** below an O-ring groove **64** above which is cut into a layer of urethane **202**. A machining slot **63** is cut into the part holder **54** to accommodate cutting tool operations. This is described in more detail below. Depending on the application other machining holes **51** may be included in the tooling fixture. In some examples a spring loaded locating pin **67** may be affixed to the tooling fixture.

In one useful embodiment the base **58** may be made from a three-quarter inch IC six aluminum tooling plate. Other materials may also be used such as fiberglass, laminates and the like. The top of the plate is ground smooth and flat and an elongated bonding epoxy is applied for bonding the pedestal to the plate. The pedestal may advantageously be made oversized for stability. It is put on the base and positioned on a vacuum table. Once the tooling fixture **50** is in place on the table, the vacuum is activated thereby holding the fixture and (not shown) part in place.

Referring now to FIG. **6**, a cut-away side view of an example of a tooling fixture made with the vacuum granular media as disclosed herein is schematically illustrated. After cutting a slot through the middle of the tooling fixture, a vacuum tube **70**, such as a ¾ inch flexible vacuum tube is inserted into the pedestal up to an outlet port **56** cut through the foam block and the fiberglass liner **60**. A small groove sized for inserting a sealing ring (commonly called an O-ring) **64** is cut into the urethane layer **202** for tightly sealing the part holding section **54** when a vacuum is applied. The O-ring groove **64** will be cut into the shape of the perimeter of the (not shown) part to be machined. After the vacuum tube is installed the slot may be refilled with or packed with foam block material.

Referring now to FIG. **7**, an example of a tooling fixture made with the vacuum granular media as disclosed herein prior to machining the granular material. This tooling fixture is shown at the stage after installing the fiberglass liner and packing in the granular material, but prior to adding the urethane layer. Note that the granular material **14** is packed with extra thickness so that it can set and be machined down to form channels for the urethane layer to be added later. The tooling fixture **500** includes a pedestal **520**, a part holding section **540**, and a vacuum port **560**. For illustrative purposes slots **542** have been left uncovered to show where the foam block was cut for the purposes of installing the vacuum tube as shown in FIG. **6**, for example.

Referring now to FIG. **8**, an example of a tooling fixture made with the vacuum granular media as disclosed herein prior to machining the part holding section for the addition of the urethane layer is shown. Here a partially fabricated tooling fixture **800** includes a part holding section **854** which is still undergoing shaping. A channel **812** has been milled around the part holding section **854** by removing granular material previously packed into the section as described above. Some foam material **820** remains in the cavity. The channel **812** is partially covered by tape or other means of damming so that urethane material can be poured into the cavity.

Referring now to FIG. **9**, an example of the tooling fixture of FIG. **8** after addition of the urethane layer by first milling out some of the granular material is shown. This will be followed by further machining of both surfaces into the final part holding shape and to introduce an O-ring seal. The urethane layer **202** is added to the channel and surrounds the granular media **14** to provide further stability and vacuum integrity to the tooling fixture.

Referring now to FIG. **10**, a more detailed side view of an example of a tooling fixture made with the vacuum granular media as disclosed herein is schematically illustrated. An O-ring groove **64** is cut into the urethane layer **202** and the mixture of the granular media with epoxy **14** is shaped to fill the part holding section **54**. The mixture is machined to conform to the part to be machined up to the urethane layer. In use an O-ring **80** is inserted into the O-ring groove **64** so that when the part to be machined is inserted it cover and will be held against the O-ring by an applied vacuum to form a vacuum seal. The combination of the urethane layer, O-ring, the granular media and the vacuum will hold a thin part tightly in place while being machined due to the gritty holding properties of the granular material.

Vacuum Forming Thermally Pliable Parts

Referring now to FIG. **11**, a block diagram of a process for vacuum forming of thermally pliable parts using porous granular media is schematically shown. Using the vacuum tooling methods described above, thermally pliable parts may be formed. At step **1101** the part is thermally activated according to 25 known methods and made ready for forming. At step **1104** the part is removed from a heating source, placed into the vacuum tool and formed into the desired shape. The vacuum tool may be made with granular media in accordance with the methods described herein. Then, at step **1106** a vacuum is applied through the granular media to pull the part into the desired shape against the vacuum tooling fixture. At step **1108** the part may be machined and trimmed as necessary.

The invention has been described herein in considerable detail in order to comply with the Patent Statutes and to provide those skilled in the art with the information needed to apply the novel principles of the present invention, and to construct and use such exemplary and specialized components as are required. However, it is to be understood that the invention may be carried out by specifically different equipment, and devices and reconstruction algorithms, and that various modifications, both as to the equipment details and operating procedures, may be accomplished without departing from the true spirit and scope of the present invention.

What is claimed is:

1. A vacuum tool for use in machining parts, the vacuum tool comprising:

a tool frame defining a perimeter of the vacuum tool, the tool frame forming a cavity;

a porous granular material positioned at least partially within the cavity, the porous granular material comprising:

a binding material; and

an abrasive granular material suspended in the binding material;

a vacuum port in fluid communication with the porous granular material and configured to facilitate passage of a vacuum pressure through the porous granular material; and

a physical seal surrounding at least a portion of the porous granular material, the physical seal having a surface extending above the porous granular material;

wherein the physical seal is configured to contact a part to be machined, and wherein contact between the physical seal and the part forms a vacuum seal between the tool frame and the part when vacuum pressure is passed through the porous granular material.

2. The vacuum tool of claim **1**, wherein the physical seal comprises an elastomer.

3. The vacuum tool of claim **1**, wherein the physical seal comprises an O-ring positioned partially within a groove surrounding at least a portion of the porous granular material.

4. The vacuum tool of claim **1**, wherein the physical seal comprises an elastically resilient membrane.

5. The vacuum tool of claim **1**, wherein the binding material is liquid epoxy configured to harden when cured.

6. The vacuum tool of claim **1**, wherein the abrasive granular material comprises one or more of: a fine abrasive rated at about 35 grit size; hardened epoxy; sintered iron; or silica.

7. The vacuum tool of claim **1**, wherein the abrasive granular material comprises non-silica, fine abrasive sand.

8. The vacuum tool of claim 1, wherein the binding material and abrasive granular material inhibit absorption of moisture.

9. The vacuum tool of claim 1, wherein a ratio of the binding material to the abrasive granular material is about 8% binding material to about 92% abrasive granular material.

10. The vacuum tool of claim 1, wherein the physical seal is arranged to define at least two separate sealing sections, each sealing section comprising a portion of the porous granular material surrounded by a portion of the physical seal.

11. A vacuum tool for use in machining parts, the vacuum tool comprising:

a tool frame defining a perimeter of the vacuum tool, the tool frame including a cavity;

a porous granular material positioned at least partially within the cavity;

a vacuum port in fluid communication with the porous granular material and configured to facilitate passage of a vacuum pressure through the porous granular material; and

a physical seal surrounding at least a portion of the porous granular material, the physical seal having a surface extending above the porous granular material,

wherein the physical seal is configured to contact a physical object, and wherein contact between the physical seal and the physical object forms a vacuum seal between the tool frame and the physical object when vacuum pressure is passed through the porous granular material.

12. The vacuum tool of claim 11, wherein the porous granular material comprises:

a binding material; and

an abrasive granular material suspended in the binding material.

13. The vacuum tool of claim 11, wherein the physical seal comprises at least one of an elastomer, an O-ring positioned partially within a groove, or an elastically resilient membrane.

14. The vacuum tool of claim 11, wherein the physical object comprises at least one of a part to be machined or a vacuum tooling fixture.

15. The vacuum tool of claim 11, wherein the physical seal is arranged to define at least two separate sealing sections, each sealing section comprising a portion of the porous granular material surrounded by a portion of the physical seal.

16. A vacuum tool for use in machining parts, the vacuum tool comprising:

a tool frame defining a perimeter of the vacuum tool, the tool frame including a cavity;

a porous granular material positioned at least partially within the cavity; and

a physical seal surrounding at least a portion of the porous granular material, the physical seal having a surface extending above the porous granular material,

wherein the physical seal is configured to contact a physical object, and wherein contact between the physical seal and the physical object forms a vacuum seal between the tool frame and the physical object when vacuum pressure is passed through the porous granular material.

17. The vacuum tool of claim 16, further comprising a vacuum port in fluid communication with the porous granular material and configured to facilitate passage of a vacuum pressure through the porous granular material.

18. The vacuum tool of claim 16, wherein the physical seal comprises at least one of an elastomer, an O-ring positioned partially within a groove, or an elastically resilient membrane.

19. The vacuum tool of claim 16, wherein the physical object comprises at least one of a part to be machined or a vacuum tooling fixture.

20. The vacuum tool of claim 16, wherein the physical seal is arranged to define at least two separate sealing sections, each sealing section comprising a portion of the porous granular material surrounded by a portion of the physical seal.

* * * * *